

METHOD AND APPARATUS FOR THE ACOUSTIC IMPROVEMENT OF THE PULSED CURRENT METHOD FOR CONTROLLING THE VELOCITY OF A TRANSDUCER HEAD

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CROSS REFERENCE TO RELATED APPLICATIONS

10 Priority is claimed from U.S. Provisional Patent Application No. 60/211,332, filed June 9, 2000 entitled "Acoustic Improvement for the Pulsed Current Method of Actuator Velocity Control Based on Sampling VCM BEMF" and further identified as Attorney Docket No. 3123-362-PROV, which is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

15 The present invention relates to controlling the movement of an actuator arm in a computer disk drive. In particular, the present invention relates to improving the acoustic characteristics of a hard disk drive during loading and unloading of the actuator arm.

BACKGROUND OF THE INVENTION

20 Computer disk drives store information on magnetic disks in concentric tracks. A typical computer disk drive is illustrated in Fig. 1. The disk drive, generally identified by reference numeral 100, includes a base 104 and magnetic disks 108 (only one of which is shown in Fig. 1). The magnetic disks 108 are interconnected to the base 104 by a spindle motor (not shown) mounted within or beneath the hub 112, such that the disks 108 can be rotated relative to the base 104. Actuator arm assemblies 116 (only one of which is shown in Fig. 1) are interconnected to the base 104 by a bearing 120, such that the actuator arm assemblies 116 can be moved radially
25 with respect to the magnetic disks 108. The actuator arm assemblies 116 each include a transducer head 124 at a first end, to address each of the surfaces of the magnetic disks 108. A

voice coil motor **128** pivots the actuator arm assemblies **116** about the bearing **120**, to radially position the transducer heads **124** across the surfaces of the magnetic disks **108**. The voice coil motor **128** is operated by a controller **132** that is in turn operatively connected to a host computer (not shown). By changing the radial position of the transducer heads **124** with respect to the magnetic disks **108**, the transducer heads **124** can access different tracks or cylinders **136** on the magnetic disks **108**.

The high rotational speed of the magnetic disks **108** when the disk drive **100** is in use creates a boundary layer of air that rotates with the surface of each disk **108**. This boundary layer is sufficient to suspend the transducer heads **124** above the surfaces of the disks **108** at a predetermined flying height. As the storage capacities of hard disk drives have increased, the flying height of the transducer heads **124** has become increasingly small. A low flying height assists in increasing the storage density of a drive **100** by allowing the magnetic transitions that store information on the disks **108** to be more tightly grouped. However, a low flying height requires a smooth disk surface, which results in increased friction between the transducer heads **124** and the surfaces of the disks **108** when the disks **108** are not rotating, thereby making it more difficult to bring the disks **108** to a rotational speed at which the heads **124** can fly. In certain instances, a "stiction event" can occur, in which the torque of the spindle motor is insufficient to break the adhesion between the transducer heads **124** and the surfaces of the disks **108**. In order to overcome these problems, disk drives have been provided with special "landing zones" having a textured surface and designed for receiving the transducer heads **124** when the disks **108** are not rotating. However, these textured areas can cause oscillations in low flying heads **124**. In addition, the provision of landing zones does not prevent actuator arms **116** from moving and

coming into contact with the disks **108**, for instance in response to shocks, and damaging the surfaces of the disks **108**.

5 In order to overcome these problems, disk drive actuator arm assemblies **116** may be provided with tabs or cam followers **138** capable of engaging corresponding cams **140** when the actuator arm assemblies **116** are in a parked position. The cams **140** each generally contain a ramp portion **144** and a detent portion **148**. When the disk drive **100** is not in use, the actuator arm assemblies **116** are generally positioned such that the tabs **136** are held in the cams **140** at the detents **148**. The transducer heads **124** are said to be "unloaded" from the disks **108** when the tabs **138** are held by the cams **140**. The terms "load" and "unload" can be interchanged, but for purposes of the present invention, "unloading" refers to removing a transducer head **124** from the disk **108** surface and "loading" refers to placing a transducer head **124** adjacent the disk **108** surface such that read and write operations may be carried out. When the transducer heads **124** are in the unloaded position, the magnetic disks **108** are protected from damage that may be caused by a collision between a transducer head **124** and the disk **108**, because the actuator arms **116** are held in place by the cams **140**.

Before data can be read from or written to the disks **108**, the transducer heads **124** must be "loaded" onto the surfaces of the magnetic disks **108**. In loading the transducer heads **124**, it is important to ensure that the transducer heads **124** are not traveling at too great a velocity. If the transducer heads **124** leave the cam **140** at too great a velocity, the component of their motion that is perpendicular to the surfaces of the disks **108** will likely be too great for the boundary layer of air to support the transducer heads **124** and prevent contact between the transducer heads **124** and the disks **108**. Such contact will likely cause a loss of data from the disk drive **100**.

Conversely, it is important to load the transducer heads 124 as quickly as possible, in order to limit the time period during which the host computer must wait before information can be retrieved from the disk drive 100. Accordingly, it is desirable to closely regulate the velocity of the transducer heads 124 during loading. During unloading, high speed is also desirable.

5 However, the transducer heads should not be unloaded at too great a speed, to avoid damaging the actuator arm assemblies when they contact the cams 140. Also, if the head travels at too great a speed, it can bounce and strike the disk. In addition, cam wear is higher if the head travels at too great a velocity.

10 While the transducer heads 124 are being loaded, the transducer heads 124 are lifted away from the surfaces of the disks 108 by the cam 140. Accordingly, information encoded on the disks 108 concerning the position of the transducer heads 124 with respect to the surfaces of the disks 108 is not available, and the velocity of a transducer head 124 cannot be determined by reading information from the disks 108. However, the movement of the coils of the voice coil motor 128 with respect to the magnets of the voice coil motor 128 produces a back
15 electromagnetic force (BEMF, or back EMF) in the coil of the voice coil motor 128. Because this back EMF is proportional to the velocity of the actuator arm assemblies 116, it can be sensed and used to determine the velocity of the transducer heads 124.

20 The back EMF generated by the movement of the voice coil motor 128 can be determined if the resistance and inductance of the voice coil motor 128 are known. In particular, the back EMF generated by the movement of the voice coil motor 128 is equal to the voltage supplied to the voice coil motor less the voltage drop due to the internal resistance and inductance of the

voice coil motor. However, this method is unreliable, as the resistance of the voice coil motor 128 changes while the voice coil motor 128 is in motion.

Another approach to reading the back EMF generated in a voice coil motor 128 has been to turn off the drive current to the voice coil motor 128 at regular intervals of time. The back

EMF is then sampled while the drive current is off. One such prior art approach is depicted in Fig. 2. In Fig. 2, a train of pulses 200 having regular pulse widths T_p 204 and varying current or voltage levels are shown. In between the pulses 200 are regular sampling intervals T_s 208.

During the sampling intervals, samples of the back EMF S_1, S_2, S_3, S_4 and S_5 are taken.

According to this approach, the width T_p 204 of the pulses is constant, and the amplitude of the pulses 200 is varied in order to adjust the velocity of the transducer heads 124. The provision of electrical power to the voice coil motor 128 is discontinued during the sampling times T_s 208 in order to allow an accurate reading of the back EMF to be taken. However, this approach results in the production of a relatively loud and objectionable audible noise due to the regular frequency with which power is applied to the voice coil motor 128.

Another approach to controlling the velocity with which transducer heads 124 are loaded onto the surface of disks 108 is depicted in Fig. 3. According to this approach, pulses 300 having a first pulse width T_{p1} 304 and amplitude V_1 308 are applied to the voice coil motor 128 in order to maintain a desired velocity of the transducer heads 124 with respect to the surfaces of the disks 108. Where the velocity of the transducer heads 124 is too great, the pulses 300 are discontinued. After a predetermined number of pulses 300 having a first width T_{p1} 304 have been provided to the voice coil motor 128, pulses 300 having a narrower width T_{p2} 312 are applied to the voice coil motor 128. As with the wider pulses 300, the pulses having a narrower width T_{p2}

312 are not provided if the velocity of the transducer heads 124 is found to be too high. Samples of the back EMF are taken at times S_1 to S_9 , when no power is provided to the voice coil motor 128. Accordingly, where the velocity of the transducer heads 124 is at or below a desired velocity, a train of pulses having a regular frequency is produced, thereby creating undesired acoustical noise. In addition, although the provision of pulses may be interrupted where the velocity of the transducer heads 124 is higher than a desired velocity, it is the velocity of the transducer heads 124 which determines whether the pulse train is interrupted or not. Accordingly, this approach does not reliably decrease acoustical noise produced during the loading and unloading of the transducer heads 124.

It would be desirable to provide a method and apparatus for loading and unloading transducer heads 124 from the surfaces of magnetic disks 108 in such a way that an objectionable acoustical output is not produced. In addition, it would be desirable to provide such a method and apparatus that allowed accurate control of the velocity with which transducer heads 124 are loaded and unloaded from disk 108 surfaces. Furthermore, it would be desirable to provide such a method and apparatus that is inexpensive to implement and reliable in operation.

SUMMARY OF THE INVENTION

In accordance with the present invention, a method and apparatus for reducing the acoustic noise output of a computer disk drive when loading or unloading transducer heads is provided. The present invention generally provides pulses of electrical power to the voice coil motor used to load and unload the transducer heads that vary in time from one pulse to the next. By providing pulses of electrical power that vary in time, the spectrum of the acoustical output of

the disk drive is spread among a plurality of frequencies, thereby reducing the noise output of the disk drive.

In accordance with one embodiment of the present invention, a method and apparatus is provided in which the period of time during which electrical power is supplied to the voice coil motor is determined by reference to a table. In particular, a counter that is incremented with each pulse is used as an index to values stored in a table. Preferably, each succeeding table value differs from its predecessor, producing a noise spectrum that is distributed among a plurality of frequencies. Each of the time values stored in the table may be associated with proportioning values for use in connection with determining the output provided to the voice coil motor during each period. For instance, the associated proportioning values may be the inverse of the time value, ensuring that, when the transducer head is at a desired velocity, the total amount of power provided to the voice coil motor is the same regardless of pulse length.

Between each period during which power is supplied to the voice coil motor, a sampling interval is interposed. Toward the end of the sampling period, after the effects of the power supplied to the voice coil motor during the preceding power pulse have dissipated, a sample of the back electromotive force (BEMF or back EMF) is taken. The back EMF is measured as a voltage, and is proportional to the speed of the transducer head. Accordingly, the monitored back EMF is compared to a target voltage that corresponds to a target velocity.

In general, if the transducer head is not at the desired velocity, the voltage measured as the back EMF will not be equal to the target or desired voltage. Any discrepancy between the voltage measured as the back EMF and the desired voltage may be applied to the determination of the quantity of electrical power to be supplied during the succeeding pulse. In addition to a

proportional control term, the controller that supplies electrical power to the voice coil motor may include an integral term to account for the accumulated velocity error of the transducer head in determining the quantity of electrical power to be supplied to the voice coil motor during the next pulse. Furthermore, the controller may include a derivative control term.

5 According to another embodiment of the present invention, the time of each pulse of electrical power to the voice coil motor is determined randomly or pseudo-randomly. For instance, the period of time may be determined by a random or pseudo-random number generator. Preferably, the pulse widths resulting from the use of random or pseudo-random number generators are bounded by upper and lower time limits. The inverse of the "on" time or
10 pulse width resulting from the use of a random or pseudo-random generator may be applied as a proportional term to the controller algorithm used to determine the total electrical or power output to the voice coil motor.

 According to yet another embodiment of the present invention, the time periods during which power is supplied to the voice coil motor progress through a series of predetermined pulse
15 widths. According to this embodiment of the present invention, the pulse times or widths may gradually increase as the controller progresses through the series, the pulse times may decrease as the controller progresses through the series, or each succeeding pulse time may simply be different from the preceding pulse time. The inverse of the pulse time may be provided to the controller as a proportional term.

20 Based on the foregoing summary, a number of salient features of the present invention are readily discerned. A method and apparatus for reducing the undesired acoustical output of a disk drive when loading and unloading an actuator arm are provided. The method and apparatus of

the present invention enable the times during which power is supplied to the disk drive to be varied, without regard to whether a monitored velocity of the transducer head is to be maintained or not. Therefore, a disk drive in accordance with the present invention ensures that the pulse width of a succeeding pulse differs from a preceding pulse, thereby spreading the acoustical energy over a wider range of frequencies. This in turn reduces the objectionable audible output from a disk drive during loading or unloading of the actuator arm assemblies.

Additional advantages of the present invention will become readily apparent from the following discussion, particularly when taken together with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagrammatic representation of a top view of a conventional computer disk drive, with the cover removed;

Fig. 2 is a diagrammatic representation of a pulse train having pulses produced at regular intervals according to the prior art;

Fig. 3 is a diagrammatic representation of a pulse train that provides pulses according to the velocity of the transducer head according to the prior art;

Fig. 4A is a diagrammatic representation of components of a voice coil motor control circuit in accordance with an embodiment of the present invention;

Fig. 4B is a diagrammatic representation of certain components of a voice coil motor;

Fig. 5 is a flowchart illustrating the operation of an embodiment of the present invention;

Fig. 6 is a diagrammatic representation of a pulse train produced according to an embodiment of the present invention;

Fig. 7A is a diagrammatic representation of a pulse train produced according to an embodiment of the present invention providing a varied output to the voice coil motor; and

Fig. 7B illustrates an example velocity of a transducer head in response to power inputs to the voice coil motor as illustrated in **Fig. 7A**.

DETAILED DESCRIPTION

Fig. 4A is a diagrammatic representation of components of a voice coil motor control circuit **400** in accordance with an embodiment of the present invention. The control circuit **400** generally includes an analog to digital converter **404**, a proportional-integral (PI) controller **408**, a voice coil motor driver **412** and the voice coil motor (VCM) **128**. In general, the analog to digital converter **404**, the proportional-integral controller **408** and the voice coil motor driver **412** may be provided as part of the controller **132**. The voice coil motor **128** includes a coil **416** (**Fig. 4B**) that is interconnected to an electrical power source (for instance the VCM driver **412**) and that can move through a magnetic field H produced by magnets **420**.

During a loading or unloading operation, the actuator arm assemblies **116** are moved by the voice coil motor **128** to position the transducer heads **124** above the surfaces of the disks **108**. The corresponding movement of the coil **416** of the voice coil motor **128** through the magnetic field H within the voice coil motor **128** produces a back electromotive force (BEMF or back EMF) in the coil of the voice coil motor **128**. According to one embodiment of the present invention, this back EMF, identified in **Fig. 4A** as signal **432**, is provided to the analog to digital converter **404**. As will be explained more fully below, the back EMF **432** is sampled by the analog to digital converter **404** while no power is being supplied to the coil **416** of the voice coil motor **128**, to increase the accuracy with which the back EMF **432** can be measured. The analog

to digital converter 404 generally compares the value of the back EMF 432, which is a measured voltage, to a reference voltage. In general, because the back EMF 432 produced in the coil 416 of the voice coil motor 128 is proportional to the speed of the coil 416 through the magnetic field H of the voice coil motor 128, the back EMF voltage can be correlated to a radial velocity of the transducer heads 124 across the disks 108. Therefore, a reference voltage corresponding to a desired transducer head 124 velocity can be established. In general, the analog to digital converter 404 outputs a voltage signal 436 to the proportional-integral controller 408 that represents the velocity of the transducer heads 124.

The proportional-integral controller 408 receives the velocity signal 436 and calculates a velocity error. The velocity error is equal to the difference between the voltage signal 436 and the reference voltage. In general, the velocity error is applied to the proportional-integral controller 408 control algorithm to determine the amount of power to be provided to the voice coil motor 128 during the next pulse. Although the use of a proportional-integral type control algorithm is preferred, it is not necessary. For instance, as will be appreciated by those of ordinary skill in the art, a proportional, proportional-derivative, proportional-integral-derivative, or any other control algorithm suitable for velocity control may be used.

The control signal 440 from the proportional-integral controller 408 is provided to the VCM driver 412. The VCM driver 412 converts the control signal 440 to a power signal 444 that may be used to power the voice coil motor 128. In particular, the VCM driver 412 may, where the control signal 440 is analog, comprise an amplifier. According to another embodiment of the present invention, the VCM driver 412 may comprise a digital to analog converter in combination with an amplifier. The power signal 444 produced by the VCM driver 412 is sent to

the coil **416** of the voice coil motor **128** to move the coil **416** with respect to the magnets **420** and to in turn move the actuator arm assemblies **116**.

With reference now to **Fig. 5**, the operation of an embodiment of the present invention is illustrated. Initially, at step **500** a count value N is initialized. According to one embodiment of the present invention, the initial value held by the counter is 0. At step **504**, the output of the proportional-integral controller **408** is set to an initial value I_i and is provided as a control signal **440** to the VCM driver **412**. At step **508**, the control signal **440** is amplified or converted to an analog signal and amplified by the VCM driver **412** and provided to the voice coil motor **128** as power signal **444**. As will be appreciated by those of ordinary skill in the art, the VCM driver **412** may be considered as either a voltage source or a current source. According to the present example, the duration or pulse width T_n of the initial output I_i may be determined by reference to a table as will be explained in detail below.

At step **512**, a check is made to determine whether the transducer head **124** has been loaded onto the disk **108** surface. This may be accomplished by determining whether valid position information is being read by the transducer head **124** from the disk **108**. If such signals are received, the transducer head **124** is loaded and the loading procedure ends (step **516**).

If it is determined that the transducer head **124** has not been loaded onto the disk **108**, the system delays for a sampling time period T_s after the previous power pulse has ended (step **520**). During the sampling period T_s the count N is incremented to the value $N + 1$ (step **524**). At step **528**, during the sampling period T_s , the back EMF is sampled. The velocity error may then be calculated (step **532**).

At step 536 the pulse duration or pulse width T_N corresponding to the count value N is determined. The time periods of the pulse duration or pulse width may be specified as absolute or relative times, or as a number of counts by a clock provided as part of the controller 132. According to one embodiment of the present invention, the time T_N during which power is supplied to the voice coil motor is determined by using a counter as an index to a table of time periods. For instance, the least significant digit or a number of least significant digits of a counter may be referenced to a table of time values. For example, with reference now to **Table 1**, a value of $N=0$ corresponds to a time value of 5. As shown in **Table 1**, the time values are different for different values of N . **Table 1** illustrates a table containing four different time values or pulse widths. Accordingly, the table values may be conveniently accessed by use of a two bit counter, or by reference to the two least significant bits of a counter having more than two bits, to determine the value N and thus serve as an index to the time values in the table. Of course, greater or lesser numbers of time values may be used.

N	0	1	2	3
T_N	5	4	3	2
Kp_N	1/5	1/4	1/3	1/2

TABLE 1

According to another embodiment of the present invention, the pulse width T_N is determined randomly. Preferably, the randomly determined time period is constrained within lower and upper time bounds. According to this embodiment of the present invention, the time may be determined by a random or pseudo-random number generator.

According to still another embodiment of the present invention, the time T_N may be determined by rotating through a predetermined sequence of times. For instance, at time $N=0$, the pulse width T_0 may be equal to 2, at $N=1$ the pulse width T_1 may be equal to 4, T_2 may be equal to 8 and T_3 may be equal to 16. At $N=4$, the pulse width T_4 may again be equal to 2 and the time values may progress back through the sequence. Of course, any desired sequence of numbers may be used. In addition, although the described embodiments feature pulses that vary from one pulse to the next, this is not strictly necessary. For example, a relatively short train (e.g., three or four pulses) of pulses having a first pulse width may be followed by another relatively short train of pulses having a second pulse width.

At step 540 the output I_N to the voice coil motor 128 is calculated. I_N may be calculated as a current or a voltage. According to one embodiment of the present invention, the calculation of I_N is performed in the proportional-integral controller 408 of the controller 132, and the appropriate control signal 440 is provided to the VCM driver 412. In general, the proportional term and any other terms of the control algorithm may be multiplied by a value K_{pN} equal to the inverse of the pulse width T_N during which the output I_N is supplied to the voice coil motor (i.e., the pulse width of I_N). The VCM driver 412 then provides a power signal 444 equal to the output I_N calculated at step 508. Because of the multiplication of some or all of the terms of the control algorithm by the inverse of the pulse width T_N (i.e. by K_{pN}), the control signal 440 may be proportioned such that, with all other factors being equal, the same total amount of power is supplied to the voice coil motor 128 during each pulse, even though the width T_N of each pulse varies. Accordingly, when the transducer head 124 is at the desired velocity, each pulse contains the same amount of power.

With reference now to **Fig. 6**, a pulse train **600** in accordance with an embodiment of the present invention is illustrated. The example pulse train **600** illustrated in **Fig. 6** may be generated using the values set forth in **Table 1**. Thus, when N is equal to 0, the pulse width T_0 is equal to 5 units. In addition, when N is equal to 0, the proportional term K_{pN} , here K_{p0} , is equal to 1/5. At $N=1$, T_1 equals 4 units and K_{p1} equals 1/4. Similarly, at $N=2$, T_2 equals 3 units and K_{p2} equals 1/3, and at $N=3$, T_3 equals 2 units and K_{p3} equals 1/2. It will be appreciated that the pulse width value T_N multiplied by the proportional term K_{pN} is equal to 1 for any value of N . Accordingly, the power supplied to the voice coil motor **128** is normalized by the proportional term K_{pN} , regardless of the pulse width T_N . Therefore, the pulse width or time T_N does not itself affect the total amount of power supplied to the voice coil motor **128** during a discrete pulse.

As mentioned above, the pulse train **600** comprises pulses having pulse lengths determined by the values set forth in **Table 1**. Furthermore, the pulse train **600** consists of pulses that each contain an equal quantity of power. In particular, the first pulse **604** of the pulse train **600** remains on for a pulse width or time T_0 , here equal to 5 units. The first pulse **604** is followed by a sampling period T_s **606**. The back EMF is sampled during the sampling period T_s **606**, preferably at a point S_1 **612** that is towards the end of the sampling period **606**.

Referring to both **Fig. 5** and **Fig. 6**, after the back EMF has been sampled (step **528**), the velocity error of the transducer head **124** is calculated (step **532**). Next, T_N is determined (step **536**). As N is now equal to 1, reference to **Table 1** provides a value T_1 equal to 4 units and K_{p1} equal to 1/4. The output I_1 to the voice coil motor **128** is then calculated (step **540**). The second pulse **608** calculated at interval $N=1$ can be seen to have a higher output voltage than the previous pulse **604**. The second pulse **608** can also be seen to have a narrower width than the

first pulse 604, as $T_1=4$ units. The total area of the second pulse 608 at interval $N=1$ is equal to the total area of the first pulse 604 at interval $N=0$. This is the expected output when the velocity error and any other inputs to the proportional-integral controller 408 remain unchanged. Of course, in operation, the amount of power in each pulse will typically vary due to the efforts of the controller 408 to maintain the transducer head 124 at the desired velocity.

As described above, if it is determined that the transducer head 124 has not yet been loaded (step 512), the system again waits for a sample time T_s 606 (step 520), during which time no power signal 444 is supplied to the voice coil motor 128. Sample time T_s 606 may be a predetermined amount of time. In general, time T_s 606 is long enough to allow any voltage remaining in the coil 416 of the voice coil motor 128 due to the inductance of the coil 416 to dissipate before the back EMF 432 in the coil 416 is sampled. Accordingly, towards the end of the time T_s 606, at point S_2 616, the back EMF 432 is sampled (step 528).

In the example illustrated in Fig. 6, it is assumed that the proportional-integral controller 408 receives a velocity error signal 436 such that it directs each pulse in the pulse train 600 to provide the same total amount of power to the voice coil motor 128. Accordingly, the third pulse 612 has a pulse width T_2 of 3 units, but the total area of the third pulse 612 is equal to the areas of each of the preceding pulses 604 and 608. The fourth pulse 616 has a pulse width T_3 equal to 2 units, but a higher output than any of the preceding pulses 604, 608 and 612. In particular, the area of the pulse 616 is equal to the area of each of the pulses 604, 608 and 612.

In the illustrated example, which receives pulse widths T_N from Table 1, N is determined by a two bit counter. Therefore, incrementing the counter from $N=3$ results in a value of $N=0$, and the pattern of pulses having widths of 5, 4, 3 and 2 units respectively is repeated. In this

way, a pulse train is supplied to the voice coil motor **128** that produces an acoustical output that comprises at least four major frequencies, and the amplitude of that output is divided among the four frequencies. This is in contrast to a conventional pulse train used for controlling a voice coil motor **128** during loading and unloading operations, which produces an audible output concentrated at one frequency. Accordingly, the acoustical output produced by a pulse train **600** in accordance with the present invention has a volume that is lower at any particular frequency, and is less objectionable than a pulse train having a series of pulses that are identical in their duration.

With reference now to **Figs. 7A** and **7B**, aspects of the operation of an embodiment of the present invention are illustrated. In particular, **Fig. 7A** illustrates a pulse train **700** provided as a power signal **444** to a voice coil motor **128**. The trace **704** in **Fig. 7B** illustrates the velocity of the transducer head **124** with respect to the disk **108** in response the pulse train **700** shown in **Fig. 7A**.

In general, the pulses comprising the pulse train **700** have one of four possible widths. In particular, the pulse widths may be determined using a counter as an index to a table (*e.g.* **Table 1**) of pulse widths and corresponding proportioning values. Accordingly, the assignment of pulse widths and proportioning values to a particular pulse may be carried out as described above with respect to the pulse train **600** illustrated in **Fig. 6**. Initially, at time 0, a first pulse **708** having a duration or width of five units is supplied as a power signal **444** to the voice coil motor **128**. In response to the first pulse **708**, the velocity of the transducer head **124** can be seen to accelerate in **Fig. 7B**. At time A, after the pulse **708** has ended, the velocity of the transducer head **124** can be seen to decelerate slightly, for instance due to friction. At point S, **710**, the back EMF in the

voice coil motor 128 is sampled. Accordingly, at point S₁ 710, the controller 132 is provided with information concerning the velocity of the transducer head 124. Because at point S₁ 710 the velocity as shown by trace 704 is less than a target velocity 712, it is determined that more power should be supplied to the voice coil motor 128.

5 According to one embodiment of the present invention, the proportional-integral controller 408 determines the power signal 444 to be applied to the voice coil motor 128 according to an algorithm that includes both proportional and integral terms. In particular, according to one embodiment of the present invention, the power signal 444 is given by the equation $I = K_p \cdot \text{BEMFError}_n + \text{Nulli}_n$, where $\text{Nulli}_{n+1} = \text{Nulli}_n + K_i \cdot K_p \cdot \text{BEMFError}_n$, and where K_p is a proportional term, K_i is an integral term, Nulli_n is the integrator value, and BEMFError_n is the difference between the measured back EMF and the reference voltage corresponding to the desired transducer head 124 velocity. As described above, K_p may be inversely proportional to the pulse length of T_n . According to one embodiment of the present invention, K_i is a fractional value.

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20 The second pulse 716 has a width of 4 units. However, the total area, and thus the total amount of power provided by the second pulse 716, is greater than the total area of the first pulse 708. In response to the second pulse 716, the trace 704 of the velocity of the transducer head 124 can be seen to increase. At point S₂ 718, a sample of the back EMF 422 in the voice coil motor 128 is again taken. The controller 132 receives this information and determines that the velocity of the transducer head 124 has moved closer to the target velocity 712, but is still below the target velocity 712. Accordingly, the third pulse 720, which has a time equal to 3 units, is provided having a total area slightly less than the total area of the preceding pulse 716. At point

S₃ 722, a sample of the back EMF is again taken, and it is determined that the velocity of the transducer head 124 exceeds the target velocity 712. Accordingly, the fourth pulse 724, which has a width of 2 units, has an area less than the total area of the preceding pulse 720.

At point S₄ 726 it is determined that the velocity of the transducer head 124 remains
5 above the target velocity 712. Accordingly, although the fifth pulse 728 has a width of 5 units, the total area of the fifth pulse 728 is much less than any of the preceding pulses, in order to bring the velocity of the transducer head 124 closer to the target velocity 712. In addition to the influence of the velocity detected at point S₄ 726, which is greater than the target velocity 712, the electrical power supplied by the fifth pulse 728 is reduced as compared to the previous pulses
10 708, 716, 720 and 724 due to the effects of the integral term of the proportional-integral controller 408, which accounts for accumulated velocity errors. At point S₅ 730 a sixth pulse 732 is provided having a width of 4 units and slightly more area than the fifth pulse 728, as the velocity of the transducer head 124 is about equal to the target velocity 712.

Of course, the particular amounts of power provided by individual pulses in a pulse train
15 such as the pulse train 700 illustrated in Fig. 7A will vary depending on the particular algorithm implemented by the proportional-integral controller 408. However, it should be appreciated that, according to the embodiment of the present invention described in connection with Figs. 7A and 7B, each pulse in a pulse train produced in accordance with that embodiment has a width that is different from the width of the preceding pulse. According to other embodiments, each pulse
20 need not have a width that differs from the preceding pulse. For instance, a train of two or more pulses having a first width may be followed by a train of two or more pulses of a second width.

In the discussion set forth herein, the pulse widths have been described in terms of "units". It will be appreciated that the pulse times selected for a particular application may be determined for that application. In addition, it will be appreciated that the particular pulse widths selected are not important, so long as the width of a pulse at any point in time is different from the preceding pulse. According to one embodiment of the present invention, four different pulse widths ($T_1 = 400 \mu s$, $T_2 = 1000 \mu s$, $T_3 = 600 \mu s$ and $T_4 = 800 \mu s$) are used. However, the number of different pulse widths and the values of the pulse widths may be adjusted to suit the particular application.

In the preceding examples and discussion, the loading of a transducer head 124 onto the surface of a disk 108 has been described. However, the present invention is equally applicable to the unloading of a transducer head 124 from a disk 108. In particular, the present invention reduces the acoustical output of a disk drive 100 during the unloading of a transducer head 124 by providing a train of pulses having varying widths. However, instead of detecting position signals derived from the surface of a disk 108 to indicate that a transducer head 124 has been loaded, during unloading, reaching a maximum current for several samples in a row, without reaching a target velocity, may be used to indicate that a transducer head has properly engaged a corresponding cam 140.

The foregoing discussion of the invention has been presented for purposes of illustration and description. Further, the description is not intended to limit the invention to the form disclosed herein. Consequently, variations and modifications commensurate with the above teachings, within the skill and knowledge of the relevant art, are within the scope of the present invention. The embodiments described hereinabove are further intended to explain the best

mode presently known of practicing the invention and to enable others skilled in the art to utilize the invention in such or in other embodiments and with various modifications required by their particular application or use of the invention. It is intended that the appended claims be construed to include the alternative embodiments to the extent permitted by the prior art.